REMARKS

Claims 28-32, 34-51, 57, and 58 are all of the claims pending in the present Application. Claim 33 is canceled above. Claims 52-56 are withdrawn as being directed to non-elected aspects of the invention.

It is noted that, notwithstanding any claim amendments made herein, Applicant's intent is to encompass equivalents of all claim elements, even if amended herein or later during prosecution.

Applicant gratefully acknowledges the Examiner's indication that claims 38 and 51 would be allowable if rewritten in independent format. Applicant has accordingly rewritten claim 38 but awaits to rewrite claim 51 until further considered by the Examiner, since it is believed that its parent claims are fully allowable over the prior art currently of record, since the prior art clearly does not recognize that HSQ can be used at close separations without use of a barrier metal to preclude diffusion of Cu atoms. The present inventor has discovered that these diffused Cu atoms are tolerable beyond a readily determinable distance from the conductor, thereby permitting the use of HSQ as an insulator at close separation without use of a barrier metal.

Claims 32-37 and 58 stand rejected under 37 USC §103(a) as being unpatentable over US Patent 6,096,648 to Lopatin or US Patent 6,121,150 to Avanzino, further in view of Applicant's Admitted Prior Art, and further in view of any one of US Patent 6,323,142 to Yamazaki, US Patent 6,566,756 to Morisaki, or US Patent 6,423,651 to Nakano.

Claims 39-50 stand rejected under 37 USC §103(a) as being unpatentable over Lopatin or Avanzino, further in view of Applicant's Admitted Prior Art and any of Yamazaki, Morisaki, or Nakano, and further in view of US Patent 6,037,664 to Zhao.

Claims 28-31 and 57 stand rejected under 37 USC §103(a) as being unpatentable over Lopatin or Avanzino, further in view of Applicant's Admitted Prior Art and any of Yamazaki, Morisaki, or Nakano, and further in view of Zhao or US Patent 6,127,089 to Subramanian et al.

Applicant respectfully disagrees.

I. THE CLAIMED INVENTION

As described and claimed, for example by claim 32, the present invention is directed to a semiconductor device including a plurality of copper (Cu) wiring lines and an insulating layer which insulates between the plurality of Cu wiring lines. The insulating layer has a surface region whose Cu concentration is equal to or higher than 10^{19} atoms/cm^3 due to a diffusion of Cu from the Cu wiring lines. The concentration decreases radially outward from this surface region in accordance with a diffusion gradient to between 10^{19} and 10^{18} atoms/cm^3 at a distance of approximately 50 nm. A separation distance between at least two of the Cu wiring lines approaches a minimum consistent with maintaining a region between these two wiring lines that has a concentration of the diffused Cu that is no greater than an order of magnitude of 10^{18} atoms/cm^3.

As mentioned in the previous Amendment, it is disclosed on page 11 at lines 11 to 20 and in Figure 4 that the Cu concentration of the surface region of the insulating layer is equal to 10^{19} atoms/cm^3. The present invention teaches that a minimal isolation between conductors is achieved by maintaining isolation between regions having concentration of 10^{19} atoms/cm^3 even though the insulation layer is subject to diffusion of Cu atoms from the conductors.

By examining the relationship between the leakage current and the Cu concentration of the insulating layer, the inventor has discovered that when the Cu concentration of the insulating layer reaches the order of 10^{19} atoms/cm^3, the influence of the leakage current will adversely affect operation of the device, but that leakage less than this amount can be tolerated, even though Cu atoms might have diffused from the conductors. Therefore, by isolating conductors with at least this amount of insulating layer, leakage current will not be sufficient significant to adversely affect the device, and minimal separation between conductors can be reduced to approach this distance even though Cu is known to diffuse into the insulation material.

In the experiment that the inventor carried out, the Cu concentration in HSQ is in the order of 10^{19} atoms/cm^3 at a position which is 50 nm or less from the contact surface

of the HSQ and the Cu wiring lines and is less than 10^{19} atoms/cm^3 at a position which is equal to or more than 50 nm (e.g., see Figure 4).

Therefore, the inventor found that if the thickness of HSQ is equal to or thicker than 50 nm, a device that is not influenced by the leakage current can be obtained. This result was found by the inventor carrying out an experiment, focusing on the relationship between the leakage current and the Cu concentration of the insulating layer. This result is not described or taught in the cited references and, indeed, the cited prior art suggests that HSQ would not be adequate as an insulation material especially at narrow separations between conductors.

The distribution of Cu concentration of the insulating layer differs by the conditions for forming the insulating layer and the conditions for manufacturing the device. Namely, the distribution of Cu concentration of the insulating layer is not unique to the insulating layer. Therefore, Applicant again submits that claims 28 to 58 are not apparent from the cited references.

II. THE PRIOR ART REJECTIONS

The Examiner alleges that claims 32-37 and 58 are rendered obvious by either Lopatin or Avanzino, further in view of Applicant's Admitted Prior Art, and further in view of any one of Yamazaki, Morisaki, or Nakano, and that claims 39-50 are rendered obvious when these six references are further combined with the teachings of Zhao, and that claims 28-31 and 57 are rendered obvious when these seven references are further combined with the teachings of Subramanian.

Applicant respectfully disagrees.

A key feature of the present invention and an aspect that Applicant considers as a significant contribution to the art is the recognition of the concentration of diffused copper into the low-k layers. More specifically, Applicant's testing has demonstrated that HSQ has a threshold concentration of approximately 10^{19} atoms/cm^3 at which leakage becomes significant and that this concentration level occurs only within a predeterminable distance from the copper components, when using, for example, HSQ.

Therefore, by observing this predeterminable distance, the distance between copper components can be considerably minimized from the separations conventionally used in the art, while preserving leakage within acceptable limits. The prior art of record fails to recognize the significance of the diffused copper concentration in these isolation materials.

Thus, the prior art fails to recognize the significance of this parameter, much less recognize that copper separation can be considerably reduced in view of this copper diffusion concentration distance, without the need for a barrier material layer. In non-limiting exemplary embodiments, the present invention allows separation of copper lines in the neighborhood of 0.2 to 0.3 μm.

The Examiner newly cites the Morisaki, Nakano, and Yamazaki references as demonstrating the separation of approximately 0.2 to 0.3 μm between conductors is known in the art.

Applicant respectfully submits that the problem with the analysis based on these three newly-cited references is that these separations are discussed without reference to application in the environment of the specific material (e.g., HSQ) of the present invention. Indeed, lines 26-43 of column 3 of newly-cited Morisaki, which reference the Examiner particularly notes in the first full paragraph on page 4 of the Office Action, clearly describes that HSQ was known in the art as having problems as an insulator material.

The Examiner notes in various places in the rejection currently of record that "... the Office is not equipped to measure the particular copper concentration ....", in reference to the concentration levels described in various claims. Applicant submits that what is actually significant is that the Examiner clearly has not been able to find reference in any of the prior art that, as discovered by the present inventor, even though HSQ was known in the art to be subject to Cu atom diffusion, thereby requiring that a barrier metal be used, the actual concentration of the Cu diffusion varies in a predictable manner such that these close conductor separations are possible even though the diffused Cu atoms are present.

That is, as shown in Figures 2-5 of the present Application, the inventor has discovered that the concentration of Cu atoms near the conductor is 10^{19} atoms/cm^3 or

higher and that this concentration of Cu atoms will indeed cause unacceptable leakage for a device. However, at distance of approximately 50 nm, the diffusion concentration is reduced to a level between approximately 10^{18} atoms/cm^3 and 10^{19} atoms/cm^3, as explained at lines 16-27 of page 11, and this lower concentration is acceptable for satisfactory insulation between conductors, even through conventional wisdom would consider that presence of Cu atoms would preclude use of this material HSQ at these small conductor separations without a barrier metal to prevent the Cu diffusion.

Thus, Applicant submits that the inventor's discovery clearly provides a contribution to the art by its recognition that, even though HSQ is known as having a problem of Cu atom diffusion, the diffusion gradient is sufficiently large so that acceptable insulation is still possible at conductor separations that are desirable in the art without having to use a barrier metal.

The prior art currently of record clearly fails to demonstrate use of HSQ at these close separations.

Hence, turning to the clear language of the claims, in none of Lopatin, Avanzino, Applicant's Admitted Prior Art, Zhao, or Subramanian is there any teaching or suggestion of:"... at least two of said wiring lines being separated from each other by approximately 0.2 to 0.3 μm", as required by independent claim 28. The remaining independent claims have similar language related either to this specific separation or related to the concentration level discovered by the present inventor to be acceptable for satisfactory operation of a device.

Because of the recognition of the significance of this diffusion concentration and its subsequent utilization in minimizing conductor separation, Applicant submits that the present invention clearly provides an important contribution to the art and is, therefore, clearly patentable over the prior art of record.

III. FORMAL MATTERS AND CONCLUSION

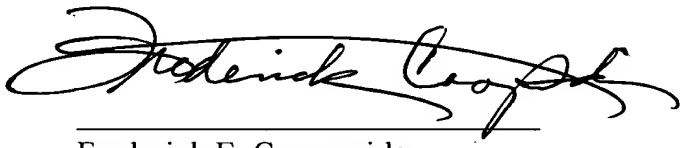
In view of the foregoing, Applicant submits that claims 28-32, 34-51, 57, and 58, all the claims presently pending in the application, are patentably distinct over the prior art of record and are in condition for allowance. The Examiner is respectfully requested to pass the above application to issue at the earliest possible time.

Should the Examiner find the application to be other than in condition for allowance, the Examiner is requested to contact the undersigned at the local telephone number listed below to discuss any other changes deemed necessary in a telephonic or personal interview.

The Commissioner is hereby authorized to charge any deficiency in fees or to credit any overpayment in fees to Attorney's Deposit Account No. 50-0481.

Respectfully Submitted,

Date: 12/27/05



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